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THE IMPLICATIONS OF THE SATURN V SYSTEMS APPROACH TO EDUCATION AND OTHER PROGRAMS

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FOREWORD

The author wishes to express his appreciation to Marshall Space Flight Center and to Auburn University for the opportunity offered by this study. The individuals delineated in the Appendix were very enthusiastic and gracious in their response to this study, and the real message is from them. However, as in any area in which science, engineering, and philosophy merge almost to a metaphysics, the author alone must of necessity assume responsibility for conclusions and presumptions. This he willingly does in presenting this material.

TABLE OF CONTENTS

INTRODUCTION

Man's first footprints on the moon and all that was required to put them there were the result of one of the most dedicated management and engineering efforts ever put forth! The "giant leap" immortalized in Armstrong's words from the moon surface was, too, a dramatic beginning of an intense, concentrated scientific effort that has many ramifications far beyond that spellbinding moment. The impact on this country, in technological capability, in world prestige, in educational influence, in motivation of large segments of our populace; and indeed, its impact on the world itself is without parallel in mankind's technological achievements to date. In fact, spin-off alone, in the form of increased medical knowledge, manufacturing techniques, management know-how, instrumentation related to pollution detection and control, and applications of this new found "ocean" of zero gravity most likely will pay many times the original investment. Additionally, the new perspective of looking at our unique earth from space has far reaching implications in more down-to-earth problems.

The problems solved in this venture were many, and were of diverse natures; technical, human, manufacturing, management, ad infinitum. In retrospect, what can one identify of this successful endeavor which would help maintain and enhance such a capability, which would also be applicable to meeting other needy requirements, and which would surely help us to

better educate future generations of technical and management people? When one considers what was done to insure the success of the Saturn launch vehicle system, many functions come to light which played a dominant role. The term "system engineering" will be used throughout this report to identify these functions. It is not meant to imply any particular organization nor any dominant role by any particular discipline of system engineers. Nor is there any claim of a Utopian application of system engineering. Perhaps a system approach would be a better term; in any event, the broadest idea of system engineering is the intended connotation, as many of the key elements of Saturn success were accomplished under various names.

Three definable aspects stand out above all others. There is little need to dwell upon them at length, but they must be considered indispensable and of primary importance in the application of any system approach - no matter what problem is being attacked! These are "must" basics:

- a well-defined goal to be accomplished within a reasonably well-defined time frame
- adequate technical specialist strength to solve the problem - intense rigor is required as complexity increases.
- computer capability of a reasonable level - if the problem is difficult enough to require a systems approach, it usually is difficult enough to require considerable computer analysis and simulation.

While these will be referred to later in this report, they will not be repeatedly emphasized in comparison to their importance. They just simply have to be there, or the chances of success will be practically non-existent!

Any attempt to identify any short-length semantics as being descriptive of the key to the Saturn/Apollo success would be only partly adequate. Just recently, 51 pages in a national journal[15] were allotted to discussing the Apollo spacecraft success essentials alone. Within the last month, the author came across a 262-page congressional subcommittee staff study[5] on a similar subject. It, of course, had much greater resources available and is a valuable corollary to this study.

A history of system engineering would in itself be an exhaustive undertaking. Reference 13 is a short overview of some of its background. The selected references give further insight into its development. Interestingly, W. F. Durand in the Scientific Monthly[9] in 1917 stated that "...one of the triumphs of the twentieth century will be the making of some effective progress toward the establishment and development of a science of the use of science."

The most important "history" included here, however, is to recognize the source of the system engineering capability of the NASA/MSFC team. Predominant here would be the "forcing function" afforded each individual by his own education and experience background which plays such an important part in shaping one's approach to solution of problems. Individual backgrounds would be too diverse to trace conclusively, but the experience gained in system design of increasing complexity under the Army Ballistic Missile Program - Redstone, Jupiter, Pershing, etc. - certainly played a

major role in the Saturn success. The inhouse capability developed over the years on such programs and on the Saturn I was a most successful training experience. For many of the team members, working together on complex systems all the way back to Peenemunde has to be recognized as being of major significance.

Perhaps one would think, in the reading up to this point, that this system engineering has been done within the confines of a single organization, or with the imposition of certain types of paperwork. Such is not the case! Only recently at MSFC has any organization been clearly identified and charged with system engineering functions. What a lesson this should be to those who, perhaps sincerely, think that organizational setups and paper requirements can do the job! There is no substitute for competent technical specialists and dedicated individuals (no matter of what organization they are a part) who strive constantly to assure success of the system. Certainly, however, organizational arrangements can help instead of hinder.

This report is based on conferences, interviews, a literature search, and personal observations. Primary among these are about three dozen taped interviews with key Saturn engineers and managers, mostly of MSFC. The appendix lists interviewees and describes study ground rules. There are several other papers which resulted from this study; while some ideas are probably duplicated, the reader may want to look at references 6, 7, and 1. Reference 6 was written during the early part of the study and perhaps

expresses the author's personal viewpoint to a greater extent than his observations of NASA/MSFC which are emphasized herein.

Hopefully, a "coherent whole" is the result, with Hayek's[12] observation in mind: "...if the results of the discussion(s) are not ultimately turned into a coherent whole by an individual mind, they are likely to be inferior to what would have been produced unaided by a single mind."

Certainly, the impact on the author has been great. The chance to see such a broad picture (especially following Ph. D. work in Engineering Mechanics and teaching in the area of aeroelasticity, structures, vibrations, and system analysis using analog/hybrid and digital computers) has been very instrumental in my development as an individual and as an engineering educator. It has reinforced considerably my personal convictions that engineering education <u>can</u> play an important role in shaping the engineering student's all important attitudes and perspective in an equal manner to his technical competence, that effective teaching <u>can</u> play a more significant role in student development, that - given the chance and the resources - technology <u>can</u> produce successful solutions to immensely difficult real-world problems.

Finally, the author emphasizes that the reader should not "raise a flag" of his particular idea of what system engineering entails as he reads this report. Rather, look at the report as a collective judgment of many key Saturn engineers and managers, of many authors from the literature, and of the observations of a broadly experienced university engineering professor.

Before reading further, if you, the reader, see little practical use of space, the following true story is appropriate (reprinted from a recent letter from Dr. E. Stuhlinger of MSFC to a nun in Africa in response to her query, "Why explore space?"):

"About 400 years ago, there lived a count in a small town in Germany. He was one of the benign counts and he gave a large part of his income to the poor in his town. This was much appreciated because poverty was abundant during medieval times and there were epidemics of the plague which ravaged the country frequently.

"One day, the count met a strange man. He had a workbench and little laboratory in his house, and he labored hard during the daytime so that he could afford a few hours every evening to work in his laboratory.

"He ground small lenses from pieces of glass; he mounted the lenses in tubes and he used these gadgets to look at very small objects. The count was particularly fascinated by the tiny creatures that could be observed with the strong magnification and which nobody had ever seen before.

"He invited the man to move with his laboratory to the castle, to become a member of the count's household and to devote henceforth all his time to the development and perfection of his optical gadgets as a special employee of the count.

"The townspeople, however, became angry when they realized that the count was wasting his money, as they thought, on a stunt without purpose. 'We are suffering from this plague,' they said, 'while he is paying that man for a useless hobby!'

"But the count remained firm. 'I will give you as much as I can afford,' he said, 'but I will also support this man and his work, because I know that someday something will come out of it.'

"Indeed, something very good came out of this work, and also out of similar work done by others at other places: the microscope. It is well known that the microscope has contributed more than any other invention to the progress of medicine and that the elimination of the plague and many other contagious diseases from most parts of the world is largely a result of studies which the microscope made possible.

"The count, by retaining some of his spending money for research and discovery, contributed far more to the relief of human suffering than he could have contributed by giving all he could possibly spare to his plague-ridden community."

SPECIALISTS AND GENERALISTS: A COMPARISON

It should be understood from the outset that (a) technical specialist strength and (b) overall system "awareness" claim an equal "place in the sun" in the Saturn success story. Lack of balance between the two spells ultimate doom for the system. It is true that the two capabilities inherently tend to draw an individual towards one or other of the "positions" making communication sometimes difficult.

Interestingly, the people who have been promoted the furthest within MSFC have usually gone through a cycle of gaining (a) and then (b); and of these, those who perhaps have had the strongest background in (a) have had an almost traumatic experience upon the addition of (b). A comparison, or actually, a contrast of extremes is alluded to in the literature by Hamilton[11]:

> "The generalist will in many instances have nothing specific to 'hang his hat on' except the fact that he understands the way in which the total business (or system) functions. ...by the nature of his job, he must maintain exceptional communication links to all parts of the (organization). He is generally better at dealing with people - motivating and communicating - than are very specialized men. The generalist does not gain anything by hoarding information or refusing to accept information from outside sources ... he is an expert at utilizing and disseminating information...
>
> "On the other hand, the specialist is selling expertise. He is a focal point of knowledge about a particular subject. Much of his purpose is to become a source of information for the company. To lose the aura of authority would be to lose the title, specialist. The specialist also never seems to generate much personal contact among people in other functions ... Associates of a specialist are usually in closely related fields... Both kinds of men are needed in all functional areas...the best men...are neither pure generalists, or pure specialists - but a combination of both."

The dilemma of conflict between these important types of men is not unique to NASA, of course. Perhaps keeping this problem from dominating the Saturn/Apollo Program is really the key to success. Of primary importance in doing this was the leadership capability and the recognized technical capability of key MSFC people. Drs. von Braun, Rees, and Rudolph and others evidently played a tremendous role in; first, having a very respected technical reputation; secondly, possessing an acute system awareness and sensitivity for opinions of others; thirdly, having a superior ability to question perceptively; and fourthly, developing the ability to follow a question all the way down to the "nuts and bolts," when necessary! They were both specialists and generalists!

This inherent conflict between generalists and specialists can be better understood by looking at a few ideas presented in interviews. One relevant idea is the contrast between difficulties associated with using instruments or devices to obtain data upon which to make a decision, and the extraction from human beings of data upon which to make decisions. This necessary change for a specialist turning generalist was described by several as "traumatic." Some felt that if any one point should be emphasized in making a systems approach successful, it would be the establishment of a well qualified group of technical experts for the management team to understand the "biases" of a group of people (biases in this use is not meant derogatorily, but is indicative that educational and professional background and development experience all play a very important part in how people solve problems).

Another contrast exists between the strong technically motivated specialist and his move into the management structure. This necessitates a change from a "do it myself" philosophy to one of being able to delegate responsibility and to select people with traits so that a manager has confidence that they can do a given job as well as he can. He must learn to compromise, too, in this role-change.

One cannot assume that all good technical specialists can become good engineering managers. And yet, as years go by, the specialist often sees that the managerial route is the only route of increasing reward. So he must decide to go that route, or accept his continuing technical role without bitterness to those who "go the other way." Could more NASA emphasis be placed on rewarding the strong specialist in ways different from the management route? In any event, management positions should continue to be filled with technically qualified people - the importance of this is attested to by the rest of this report.

On the other hand, at the entering level, it is precisely the narrowly educated specialist that NASA seeks the most. A quote from the president of Dupont[17] is very appropriate here:

> "The call for generalists has become conventional wisdom - almost a cliche' - but there is an open question about our effectiveness in answering that call. The call will be met only if industry (NASA?) lives up to its public pronouncements, places a premium on breadth, and provides inhouse, or in cooperation with universities, opportunities for technical men to build both their broad-scale and specifically technical talents. If we truly want broad-gauge men and women, we must provide jobs that challenge their intellects and an environment conducive to their ideals and aspirations. Otherwise, we will be saddled with mediocrity, and deserve the sad fate that mediocrity will bring us."

Still, as one interviewee commented: "It might be, that to be a generalist, one should have demonstrated specialist ability first..." Perhaps such a demonstration though, could come in the years of technical education, or could occur parallel to an acute "system awareness" development rather than in what often occurs - "technical island" development.

Reference 6 by the author points out that the system engineer idea has been likened to the letter "T" signifying depth in one field (at least), but breadth at the surface. A well formed T would be best; no vertical member and the T becomes just a dash, a very shallow education. However, with no horizontal member on the T, it becomes an "I" and the person looks only at <u>his</u> specialty, <u>his</u> ideas, <u>his</u> solutions; and organizational objectives become shaped in personalities, power politics, and personal whims rather than the search for the realistic best solutions.

The need for more of a balance between generalist traits and specialist traits should not be interpreted as encouraging less depth, or less technical capability. If there was <u>one</u> consensus item from all the interviews conducted, it was the equation:

MSFC technical specialty strength = Saturn success

Reference 24 documents this in a more quantitative manner.

A HISTORICAL PARALLEL?

The status quo is not an assurance of continuing success. An interesting parallel exists in Toynbee's analysis of history[26] (perhaps one of the best observers of history "systems" to date) and NASA's pattern up to now. Figure 1 compares some of the appropriate parallels to a point. Whether NASA is at the "peak," or will follow the parallel from the "peak" on, remains to be seen, but the warning should be clear.

Toynbee also cites that, among other things,

(a) the decay of technical achievement has been a result, not a cause, of breakdown (of a civilization),

(b) imitation is the only way in which the "uncreative majority" can follow the leadership of the creative leaders, and

(c) a real danger exists in the leaders becoming "infected with the mechanicalness of their followers" (leading to an "arrested" civilization).

Also, "history shows that the group which successfully responds to one challenge is rarely the successful respondent to the next ... those who have succeeded once are apt, on the next occasion, to be found 'resting on their oars'." Finally, Toynbee points out an example in which a civilization "failed because, intoxicated by its own success, it was tempted to make illegitimate use of political weapons in pursuit of inordinate aims." The point here is that parallel in growth is without question; therefore, the warnings of history should be appropriately recognized! Any successful organization must especially guard against loss of its creative capability.

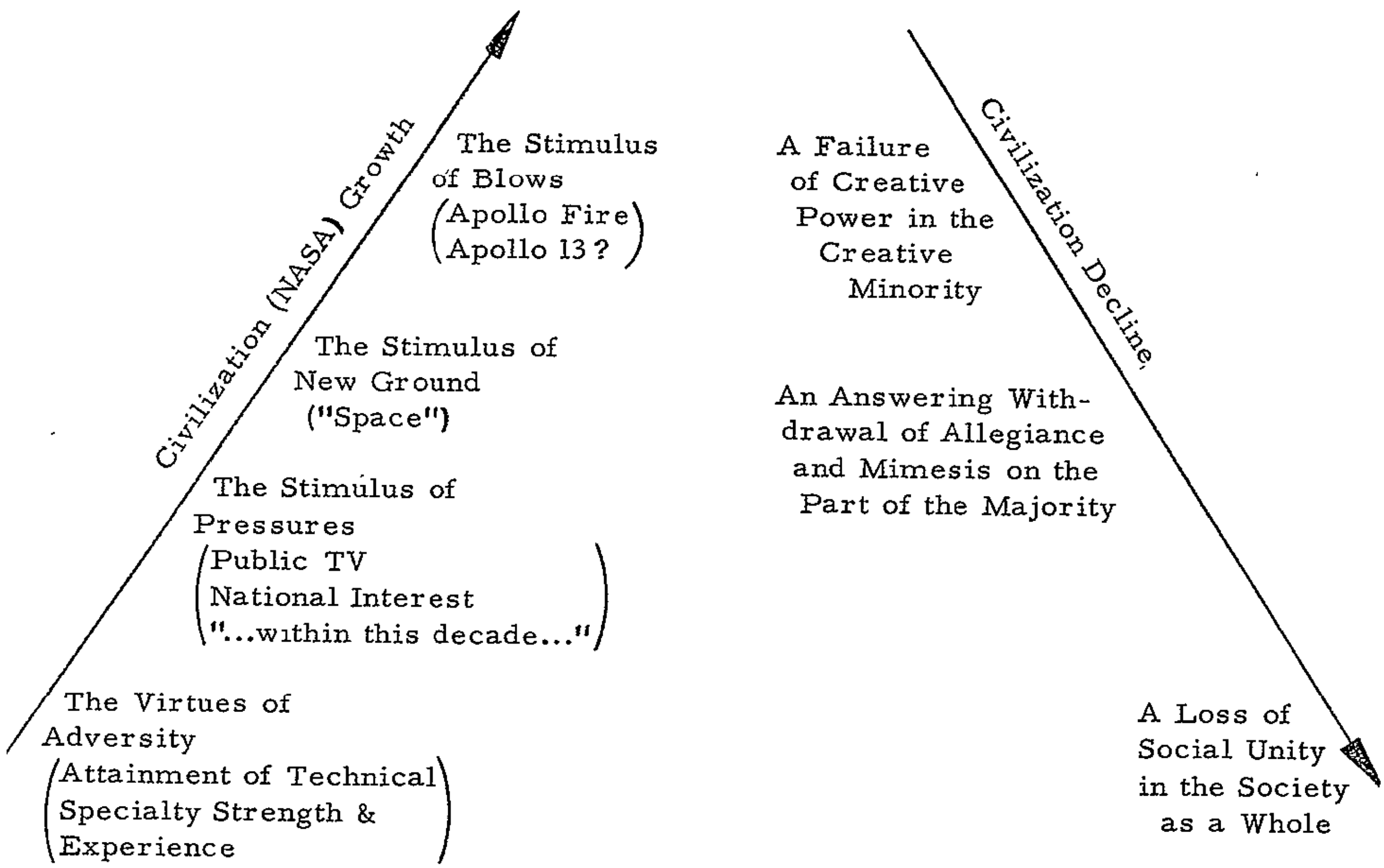

FIGURE 1. PARALLELS IN CIVILIZATION GROWTH AND NASA GROWTH; WARNINGS OF CIVILIZATION DECLINE

Marshall System Approach and System Engineering

System engineering can be defined as:

> The process of applying science and technology to the study and planning of a system so that the relationships of various subsystems are fully established before designs are committed.[20]

Other references break this process down into a sequence of events for further illustration. Many other definitions could be promoted (see ref. 6, for instance), but only a slight modification of the above seems desirable based on the Marshall interviews, with perhaps the systems approach a slightly preferable label:

> The process of applying science and technology to the study and planning of a system so that the relationships of various subsystems are thoroughly explored before designs are committed, and so that a large amount of flexibility is built into the design for difficult-to-foresee performance requirement changes.

Continued success of the Saturn vehicle and adaptability of the system to unforeseen missions are a striking testimonial to this process - by whatever name under which achieved! Of course, everyone has 20-20 hindsight; the fact that few have similar foresight requires the obtainment of all the flexibility possible. Just as it is usually the "unloaded" gun that causes most gun accidents, so it is with problems with the system - so often it is the problem not thought of that "rears its ugly head" or "falls through the cracks"! Built in flexibility can ease the impact when such things become apparent. The recent Apollo 13 incident is a tremendous example of this flexibility. One-engine-out capability, and the capability to perform a yaw maneuver at

lift-off to compensate for less than originally planned-for swing arm retraction rates, are good examples, too. Certainly redundancy, modularity, the clustered engine concept, and capable guidance systems all contributed to the Saturn flexibility features. The computer capability with its quick response time must be considered an eminent prerequisite to reanalysis and quick decision capability when necessity arises.

Explicit, detailed, step-by-step procedures as a follow-on to the definition are the usual approach in most system engineering articles. Perhaps, first, one should differentiate between system analysis, systems management, and what we might call -- technical system engineering. It is assumed that system analysis includes the mathematical modeling or other simulations which are required to analyze the response of a system. It is something you do after defining fairly explicitly - a system or a subsystem. It comprises numerical methods, optimization techniques, computer techniques, and numerous specific discipline approaches. Systems Management comprises the organizational and management structure; procurement, schedule and cost aspects; and in general the activities peripheral to explicit engineering activities. Technical systems engineering is much more difficult to identify due to (a) the subtleties involved (see ref. 7), (b) the interrelationships required, and (c) the wide divergence of opinion held by so many people of its merits, need, or advantages. The remainder of this section is devoted to trying to convey in as succinct a fashion as practical - many of the thoughts expressed by key NASA/MSFC people. Many textbooks and papers document ordered processes involved in systems

engineering [4, 16, 22, 25]. The final part of this section summarizes the "Marshall Circle," or ordered process, but no consensus exists within Marshall technical management on explicit semantics of this at present.

Summary of Desirable Influences

There were a number of influences, desirable and undesirable, which had an impact on technical system engineering of the Saturn. They are presented here in certain categories in order to attempt to structure their presentation. Order of importance is not implied in numbering them. Occasional use of quotes are for appropriate interview comments and for Saturn or technical "slang" which best puts across certain ideas. As an example of typical contrasting influences and the necessity to suppress some while nurturing others, Figure 2 serves to point out their importance in reaching singleness of purpose. This section is followed by a summary of undesirable influences which is then followed by another section of other identifiable influences (which could not be adequately or succintly described in the summaries).

It is difficult to categorize all desirable influences, but one important category can be called attitude. Some of the outstanding ones were attitudes toward:

1. System awareness -- This was an intense overall perspective possessed by dedicated individuals who realized the necessity for cooperative efforts on subsystem development in order to assure success of the overall system.

2. Technical issues -- The concentration on these by management, working groups and panels, laboratory discipline groups, and in program reviews was without letup. Individual perceptive

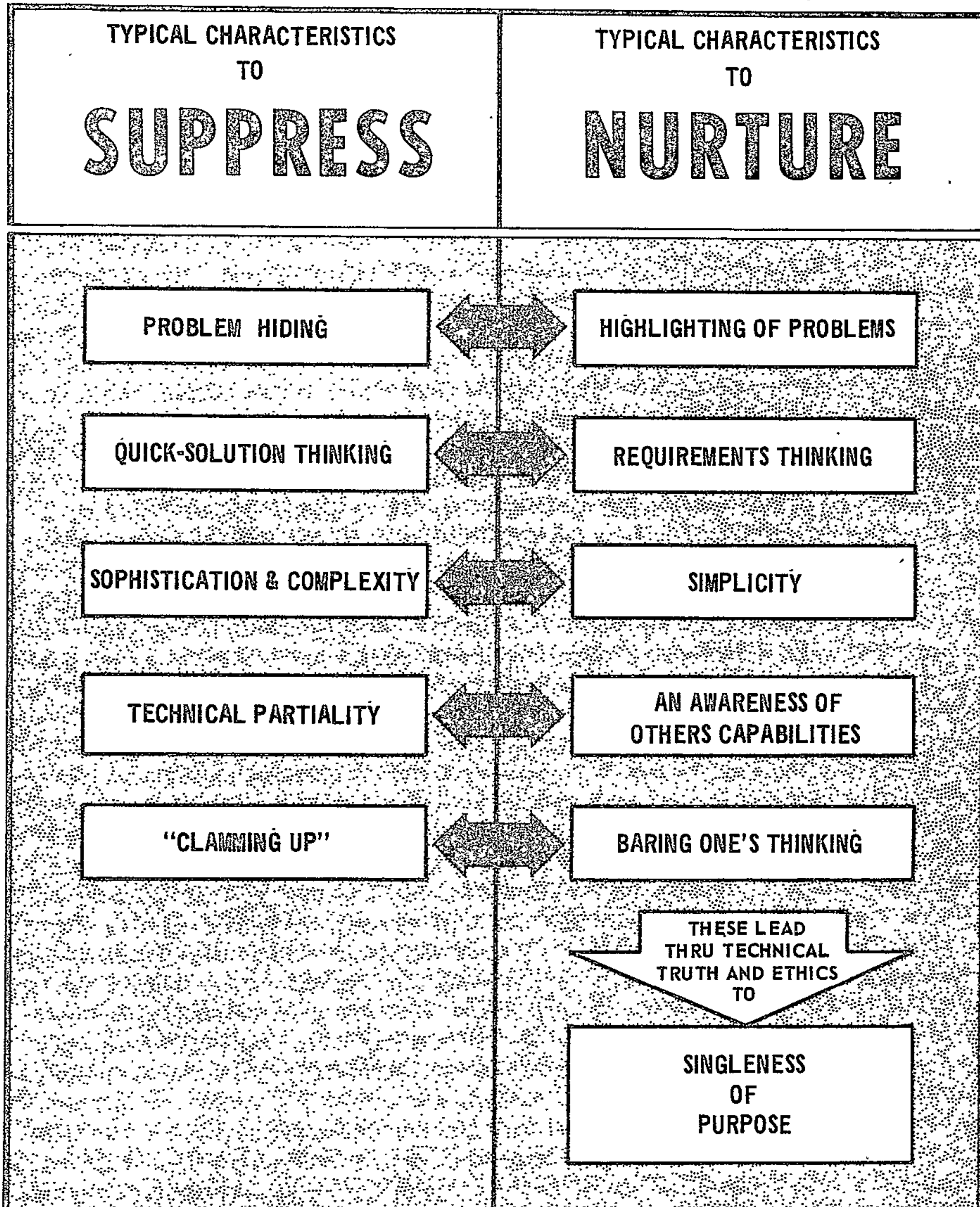

FIGURE 2.

CONTRASTING INFLUENCES ON SATURN TECHNICAL SYSTEMS ENGINEERING

questioning and addressing problem issues in "recovery plans" played a very important part.

3. Flexibility -- A recognition that this had to be an important part (a) of system development, (b) in meeting system requirements, and (c) in adapting to unforeseen requirements was essential. This was indicated by many key decisions (clustering of engines, earth orbit-lunar orbit mission "plateaus", digital launch tape, etc.) and a realization that "fix it until it meets the specifications" might not be the best attitude to have. The "pay off" has been very evident, for instance in the "slingshot" maneuver and in the safe return of Apollo 13 following a catastrophic failure.

4. "Accepted risks" -- This was an attitude which not only meant agreeing to do things (at least tentatively) in some less-than-Utopian manner, but also meant recognizing the necessity to "jump in at mid-stream" in attacking many problems. ("Things can nearly always be done better in a more sophisticated manner, and rarely does one get to attack the problem from the optimum beginning.")

5. Specialist communication -- This was an attitude which allowed "the individual technical specialist to scream within the framework of the overall program--within his discipline--when he did not think (or know) that something was going correctly;" which allowed him to run a test program when questions arose.

6. Technical truth -- An attitude existed which placed final technical authority in discipline laboratories when conflicts reached a stalemate. Program constraints of time and cost were not allowed to inhibit or close out search for technical truth. When conflicts could not be settled, it was confidence in the individual technical man closest to the problem which "ended" the search for the needed technical truth.

7. Failures -- A controlled failure attitude necessitated constantly promoting the idea, "let us do all we can to prevent any and all failures, of course; but if one occurs, what do we do then?" Too, failures were "planned for," or anticipated. It was assumed some would occur in testing, for instance. No failures were left unexplained!

8. Work environment -- Individuals were allowed to "pursue their own specialty in the framework or the environment of several specialties and yet to see how all of these fit together so as to come out with something good collectively."

9. Automatic responsibility -- Automatic assumption of responsibility concerning discipline areas on Saturn by laboratory technical management was very significant. There was no wait for work orders, program management, etc. This resulted in the earliest possible attack on problem areas.

10. Discipline -- "All elements were structured to provide the kind of discipline which forced the right kind of actions to be taken by everybody on both sides--government and contractor."

11. All success planning -- The "all up" concept promoted by Dr. George Mueller of NASA Headquarters was a contrast to the human tendency to do things sequentially--a prove/add, prove/add sequence of development. This concept put the same pressures on the development of every subsystem in the Saturn "stack" concurrently.

12. Testing -- Every job rendered perfectly along the way would have rendered this a useless task, but a realistic attitude required extensive testing of nearly every conceivable nature in order to assure success.

13. Post flight and post test evaluation -- No mission or test firing occurred without being followed by an intense effort to extract all possible technical considerations from available data.

Numerous specific techniques were used which had desirable influences on Saturn. Many of the more quantifiable and technical techniques are documented to some extent in the literature today. Their necessity is without question. But, interestingly, interviews identified the following broad techniques as being just as instrumental in successful engineering of systems:

1. Optimal technical solution identification -- This function, performed by laboratory discipline groups or under contract, postulated optimal solutions in the sense that the best solution without time and cost constraints was theoretically optimal.

2. Solution tempering -- The practical realization that cost and time constraints had to modify the optimal solution usually resulted

in modifications to more realistic solutions, but never to the point of violating technical integrity. This resulted in a sort of technical "check and balance."

3. Early consideration of long lead-time activities -- The initiation of planning for such activities prior to final definition of the system "headed off" many down-the-road problems and was very instrumental in meeting goals in relation to schedule in particular. For instance, the development of tooling and capability to manufacture large metal ingots and large propulsion tanks, starting construction of test sites, quality assurance and logistics planning, determining test stand needs, and planning for cryogenic distribution systems are a few examples. Much of this planning was accomplished outside of project engineering groups who probably would not have gotten to such planning early enough.

4. Traceability development -- Documented traceability of all system hardware was essential (a) to trace trouble quickly upon improper functioning and (b) to locate similar items for further investigation or replacement. Paperwork was the essence of this traceability! A delicate balance between too much and too little is mandatory.

5. Individual responsibility documentation -- In addition to project responsibilities, horizontal responsibilities were assigned to individuals and documented for all to see in the Saturn control room. Function, software, and hardware responsibilities were included. Reputations, corporate and individual, were "laid on the line!" This helped "all to play to the same sheet of music."

6. Phased project planning -- This "grew up" during the middle and end phases of Saturn as people began to appreciate how things might have been if a new start had been possible. The four successive phases of (a) preliminary analysis, (b) definition, (c) design, and (d) development and operations are a real appreciation for a systems approach.

7. Unique working relationship -- Contractor and MSFC efforts reemphasized the old adage that "two heads are better than one!" Government test programs concurrent with contractor hardware development were very important. MSFC technical capability was "on call." Their "deep penetration" into technical issues with contractors was resented at first, but at last deeply

> treasured. The Saturn program success is a real testimonial that system evolution occurs faster under such an arrangement as the MSFC-contractor working relationship. "Things were sometimes done that were wrong, but everybody got a crack at making it right. Then, the right people got together in the right room at the right time and solved the problem."

Inherently unique to the Saturn program were several important desirable characteristics. For instance, the digital launch tape was an extremely important feature which enabled a major portion of critically timed sequencing of events at launch to be placed within a piece of computer software. This could then be checked and rechecked and modified without major rework. Akin to this was the intense effort to monitor critical measurements in relation to predetermined "red line" values during mission countdown and throughout the mission.

Inherent to the missions was the fact that it lended itself to thorough mission analysis on each piece of hardware for each mission. Essentially this was done by the establishment of performance requirements by system oriented individuals who were mostly in program management, in the laboratories, or with contractors.

Schedule "launch windows" were the basis for mission schedules. Everybody knew this and they became a primary motivation as all other assignments were extrapolated back from mathematically based launch optimum times. Tremendous costs in dollars and national prestige were known to be the result of missed launches.

Manned space flight helped each worker identify vicariously with each astronaut. It was not hard to get each person to ask himself,

"Would I bet my own life on the quality of what I am doing?" Calculated motivation schemes like the Manned Flight Awareness Program played an extremely important role in success. They were definitely not a frill!

Once the program was begun, political interference was always at a minimum. The necessary time span required to accomplish major goals made this imperative.

There were constant efforts to "keep the lines open" in all internal communications between technical and management sides, between NASA centers, and vertical and horizontal within involved organizations. Continual emphasis was given to "prevent parochial atmospheres from forming," and to prevent "funnels at the top" from developing. Extensive telephoning, travel, etc. had an important impact. Intercenter communica tions were eased whenever people from one center were used to help start other efforts. This was especially evident in the MSFC-KSC relationship.

"Tiger teams," short term appointments of capable individuals with related interests and diverse disciplines, were often used to pull together more needed facts to aid in joint assessments on just where problems were most likely to be. Reviews of such assessments occurred periodicall

Finally, significant miscellaneous good influences were (a) testing and engineering analysis before really having to, (b) the "easier" trade off decisions promoted by firm goal definition and "tight" time schedules, and (c) widespread application of any known experience (internal or externa to MSFC) related to hardware problems.

Summary of Undesirable Influences

The largest group of these undesired, but ever present, influences could be categorized as tendencies which relate to the following:

1. Presentation of a false front -- There is a "human tendency to present only the 'goodness' of things and not the 'badness'. People will cover up the problems, waiting for someone else to slip the deadline date." The reluctance to admit "being in over one's head" was very real, individually and corporately.*

2. Organizational prejudice -- Organizations often arrived at "positions" to elevate their own importance more than to really search for technical truth.*

3. Ultra-conservatism in planning -- People tended to protect themselves from blame for failure, especially in "pushing to do it differently" in the early planning stages.*

4. Forgetfulness of required rigor and depth -- Memories had to be refreshed concerning the intense rigor and depth of analysis, simulation, testing, etc. which had been required to arrive at realistic solutions on pre-Saturn programs. "Dead ends" and failures in Saturn development were the most effective "refreshers

5. Trade off narrowness -- Too small a look at interfaces in trade off analyses were continually guarded against. "One must continually look closely at the interface, then back off and look again at the total system." "Nuts and bolts" queries resolved this.

6. Single level systems thinking -- There was without a doubt an intense need for multiple levels of system engineering application. For instance, the Apollo fire showed the need to take a real close look at all details for second order effects at all levels; it "embarrassed everyone into a new diligence!"

7. Ultra-sophistication -- There is a natural tendency to complicate or "sophisticate" rather than simplify. "Technical people were often required to justify why something could not be done more simply." Intense reliability and quality questioning tended to

*These were not often attacked directly. When they showed up, they suffered from silence or lack of an advocate.

counteract this phenomenon. Realization that reliability analyses had not been made or assessed demanded a relook!

8. Loss of pride of accomplishment -- The de-individualization of many types of production work often led to a loss of incentive for individual pride of accomplishment. Motivation through communication and manned flight awareness overcame this.

9. Unconcern for procurement detail -- Technical people, especially, tended to think that they could be unconcerned with procurement problems. Experience taught much, but a real problem still exists.

Undesirable inherent influences exist in any large technical organization. While those below may not be unique to Marshall experience, at least they did not dominate the Saturn program. Chief among them were:

1. "Grey areas" -- There were many difficulties which existed in deciding or showing just where the system people's responsibility ended and where the specialty element's began, both for laboratory systems people as well as for other systems people. Solutions were based on joint assessments to arrive at a consensus.

2. Trade off inconsistencies -- People trained and skilled in making the technical trade offs in optimization studies who also have the cost and contractual "feel" for trade offs were rare, but the "conflict" which resulted from those on "both sides of the fence" was a healthy one.

3. Program requirement/performance specification incompatibilities - "It is nearly impossible to get program requirements to the same degree of rigidity which is desired for end item performance specifications," but an intense effort has to be made.

4. Lack of communication -- Getting the critical facts out of human beings is in marked contrast to most experimental and analytical procedures. As one technical manager stated: "This requires a knowledge of what the 'guy' is talking about, the rationale he is using, as well as a knowledge of his background."

5. Trade off specifics vs generalities -- It is very difficult to put trade off capabilities into general requirements. Such a capability starts only in the system definition state. Eventually, the questions

must be answered; "What is expected of each subsystem in terms of failure probability? What accuracy is involved? What happens upon failure? How are repair and logistics accomplished?"

6. Lack of multiplicity of complimentary solutions -- "Of three or four different solutions to specific design requirements, only one is probably complimentary to the way that other people are solving their problems."

7. Shiftwork disadvantages -- The increase in traceability difficulties and an opposite effect from the desired pride of accomplishment were natural consequences of shiftwork. Paperwork and "staggering" may help, but the disadvantages still exist.

8. Interface definition resistance -- "Interfaces must be identified as early in a program as possible, but many engineers (particularl those in research) want to leave themselves a freer hand for 'downstream' changes."

9. Lack of reward for non-hardware products -- The emphasis had to be upon hardware, considering the goal of the Saturn program. Therefore, the less viable products like software, reliability, and planning, while indisputably contributing significantly to the whole, often went unnoticed.

10. Quick-solution thinking -- Educational development and successes and failures in their experience tended to make most individuals arrive at solutions as quickly as possible, solutions which were usually closely associated with their background. Constant effort had to be exerted to keep thinking requirements, encourage creativity, and strive to reach a solution that was best realisticall)

11. Technical bias -- A "not invented here" attitude continually reared its head in Saturn development. Impartiality in technical matters is a very difficult state of mind to reach. The proper frame of mind is to ask if the approach selected can do the job within the system constraints regardless of a preconceived notion of how it ought to be accomplished.

12. Inadequate planning-to-project information transfer -- Paperwork has been the prime transfer mechanism. Constant emphasis has had to be placed in this area for this to be efficient. It is far from what all concerned would like it to be!

13. The assumption that technical ability = management ability -- Promotions were often based on this assumption. Without question, it has been often true, but instances where it was false led to problems. In any event, the transition of the individual from the technical to the management side is rarely made without immediate loss in a group's technical ability offset by only a gradual increase in management efficiency for a certain period of time.

Another category which includes undesirable influences on Saturn or any large system development effort could be called systems considerations. They include:

1. Status monitoring resistance -- Efforts needed to monitor the status of how the engineering of the system is "coming along" seem to meet with less cooperation than those concerned with monitoring of how the subsystem is "coming along."

2. Significant factor omission -- The difficulty of identifying all factors which affect the realistic solution in a system study is very real. There is a "need to do more studies that consider evaluation in the light of searching for the right answer except for certain influences, followed by consideration of how to reshape the solution with respect to them."

3. System group obscurities -- How many good subsystem people should be moved to a systems group? Where should system groups resources come from? What should differentiate between systems functions and program management?

Finally, some knowledgeable technical managers have estimated that it may take from three to five years to develop a group of strong disciplin people with persuasive personalities who can do good systems work. Obviously, all systems work cannot be within one organization (some have conjectured that if an attempt was made to do this, organizations devoided of systems capability would just develop it anyway). The time lag in establishing the real communication links between organizations

(both within MSFC and in MSFC-contractor relationships) that were required for effective engineering of systems were detrimental to program progress.

Other Identifiable Mechanisms and Influences

The previous section has summarized many influences which were present during the Saturn Program. There are other influences which cannot be appropriately covered in any way except in expository form. Surely, volumes could be written concerning each of these; but the importance of each and their appropriateness to other system approaches is conveyed in the descriptions which follow.

Leadership Characteristics

Key leaders were instrumental in the Saturn success. Primary among their traits are (as pointed out in a previous section of this report): having a very respected technical reputation, possessing an acute system awareness and sensitivity to opinions of others, having a superior ability to question perceptively, and developing the ability to follow a question all the way down to the "nuts and bolts" when necessary. Although these are primary in importance, there are other traits that played an important role; as one description of a now retired leader indicates:

> "He had a good background, he understood Marshall, he understood people, he understood strengths and weaknesses. He was sincere and honest; people could talk to him about problems. He had that human

attribute that kept problems from being hidden from him. Maybe openness is the key ... this shortened the learning curve so that we got up a full head of steam quickly."

The magnetism of genius is very evident in a meeting with these individuals. But it is deeply more significant than popularity, or showmanship, or their "being a good guy." If there is a creative minority, as Toynbee refers to[26], these are some of them. And our nation and our technology will always be in debt to that creativity so necessary for man's first ventures into space. Alone they could not have done it, certainly, but scores - without them-without their creativity - would have failed as well.

Departure from our societal concept of "leaders" took place in the Saturn Program to some extent, too. While many functions were perhaps carried out in "the boss said so" fashion, more often it was the atmosphere provided by management to allow a group of technical specialists (MSFC and contractor) to collectively assess technical data in arriving at technical truth that led to most decisions. Desk pounding, do-it-this-way, was not the order of the day. Age, rank, and position had little to do with one's importance in these technical assessments! Certainly, there were many times when technical management made many critical decisions somewhat unaided, but their recognition of the technical advice from "below" them was of the highest esteem, and was rarely overruled.

The single-individual influence and importance cannot be overemphasized in this day of corporate anonymity. Toynbee has observed:[27]

"...up to now, creative acts in the fields of thought ... have been the achievements of single minds ... only single minds can think thoughts and express them ... There have never been such things as

collective thinking and "collective writing" (in the sense that collective work is limited by the best mind among its members).

"But I am still more impressed by the inability of an intellectual engineering enterprise to achieve, by teamwork, the result that (physical) engineering enterprises do achieve by it. A product of (physical) engineering teamwork - a bridge, dam, liner, battleship, or skyscraper (or a Saturn) - is a structural unity. In work done by an intellectual team, the contributions of the single minds do not produce a structural unity..."

Herein lies a startling recognition of systems-thinking troubles from a non-engineer and a non-scientist, but one who has searched diligently for truth in our world historical "system." The hardware is the congealing point, the test to see if we've done our intellectual job properly. It is an extremely subtle and difficult job to sway intellectual positions and to arrive at intellectual collective judgments that eventually lead to system unity!

Matrix Management

Matrix management, or some other similarly described concept, has b the subject of several studies (see, for instance, ref. 8). The major empk sis it seemed to receive on Saturn can be stated fairly briefly. Essentially (and perhaps oversimplifying) this refers to the vertical and horizontal structuring of the organization, at least in concept, so that an analogy to a mathematical matrix is conceived. Usually, the vertical responsibility is with the "line" or hardware, or project elements of the organization. The horizontal, or across-the-board, responsibility includes those staff functic which have applicability to most, if not all, of the project elements themse In the case of Saturn, vertical elements consisted of the S-IC, S-II, and

S-IVB Stages, the IU, and vehicle GSE, etc.; the horizontal functions included testing, quality and reliability, systems engineering, program control, etc.

There are natural tendencies, many of which have been mentioned elsewhere in this report, which tend to influence management to put most of the responsibility in the vertical structure (schedule commitments, easier to see "products" of hardware, etc.). Often lip service only is given the horizontal elements. Much of the Saturn success would have to be attributed to management's "equal treatment" of horizontal and vertical structures. One very important manner in which this was done was in monthly 2-day program reviews. The first day was given to the vertical elements in "speaking to their problems"; the second day the horizontal functioning groups addressed theirs. Management listened to both! Interestingly, the natural tendency of not wanting to talk of problems had to be overcome - individuals thought they would recover and soon solve their problems. The required presentation of a recovery plan proved a tremendous forcing function in problem resolution. The extremely difficult to-document tie of visibility, openness, and communication and the role of individual genius in these just described functions were very instrumental to success.

Finally,. this matrix idea pervaded the NASA-contractor relationship. Contractors were essentially the vertical elements with full responsibility for developing the hardware; NASA/MSFC filled the horizontal role to an

extent, using their pre-Saturn and early Saturn experience to help avoid pitfalls and integrate the various contractor efforts.

Visibility

In the engineering of complex systems, there is a consensus among most technical MSFC managers that good visibility plays a dominant role. It will not take the place of "eyeball to eyeball" communication, but it can augment the communication and problem highlighting functions of any organizational efforts. More though, than any of these identifiable mechanisms, visibility must be individually tailored to the system.

What identifiable and transferable traits of visibility can be "written up" then? One is the means to show visually trends which develop. Another is that, to be effective, nearly all visibility must be with respect to time. A third is that the inability to depict a problem visually (through the use of a chart, graph, illustration, etc.) and to discuss it effectively in front of a group may be, and most probably is, an indicator of not having a full enough understanding for effective solution.

With trends emphasized more than "status reporting," problems may be highlighted early enough to shift resources or concentrate effort on correcting an undesirable trend. The inclination to replace some missed date with a new estimated date must be circumvented so that date slippages continue to "show up." In essence, "know what you are trying to do (the plan) and know how you stand in getting there."

Visibility efforts within MSFC are not particularly unique, but they have not, in most instances, been relegated to frills or when-we-have-time status. Instead, the support necessary to give them major significance has been there. Austerity measures on follow-on programs could produce severe problems if shortsightedness cuts down on attention given this extremely important, but difficult to measure, attribute of successful engineering of systems.

The author is well aware of the detriment attributed by too much chartsmanship, the difficulty of keeping up-to-date visibility, and of the human tendency to often equate good management to complexity and quantity of charts and graphs when often such is not the case.

Verbatim comments concerning visibility were many. Some of them are:

> "Anything that has complexity and bigness, will also have failure rate problems, quality problems, delays, aborts, it will be a real 'can of worms' ... problems cannot be avoided, so they must be made visible, they must be 'flushed up,' you must force them 'out of the underbrush,' ... monitoring and communication problems are tremendous."

Flexibility of any such visibility must be stressed. There is a very delicate balance between too little, just enough, and too much! An Air Force report pertaining to lessons learned from management surveys of Air Force contractors[2] states in one of the more engineering-oriented lessons that there was:

> "extreme difficulty of timely, accurate communication between large numbers of designers who have been educated and specialize in different engineering disciplines and fields of technology ... important engineering functions are unaccomplished and not detected until highlighted as a problem."

What more evidence of lack of visibility could one find? And while Saturn experienced its share of similar problems, its ultimate and continuing performance speaks for itself!

Working Groups, Task Teams, and Trade offs

Vital to successful engineering of the Saturn system were the functions performed by groups composed of NASA and contractor technical personnel. The keyword which summarizes these successful efforts is multidisciplinary So many decisions are inherently affected by things which single discipline people do not often think of, that some type of mechanism must be used to effect interchange and communication.

It would be easy to paint a Utopian picture of working groups, etc. But, they have been the subject of much criticism and disdain. They were, however, considered successful enough by many for continuance in some form of panel, subpanel, or group on present ongoing projects. The indisputable fact remains that - single discipline groups cannot "go off by themselves" and expect to achieve success upon eventual functioning of the entire system!

Working groups were not so much thought of - in their original conception as a system engineering function; they just seemed to be the best way to do the job. But in retrospect, there are probably many examples around us of failure of some "system" because the functions performed by the working groups do not get accomplished. For instance, such functions performed by a working group of sportsmen, recreationists, wildlife managers, sanitary engineers, industrialists, and water resource people would certainly

have arrived at non-pollution of any river as the best solution to a problem. Instead, we have seen industrialists make the decision to pollute many streams (without cognizance of or proper attention paid to "working group" recommendations) - probably because government was too timid at the time to enforce pollution measures on all, therefore giving those who took the steps to stop pollution an unfair economic disadvantage. Now we must all pay.

In any event, the functions of the working groups are characterizable as follows:

(a) Groups were interdisciplinary, but assigned areas were fairly specific (e.g., guidance and control, aeroballistics). Contractor members were most effective and most valued for their depth of technical specialization rather than their loyalty to a corporate "position" or bias.

(b) Many fundamental decisions of a technical nature were made by these groups (in contrast to individual technical or management decisions). Decisions were, in effect, the "life" of these groups. Everything was dedicated to arriving at the means of quantifying things to the point where good decisions could be made.

(c) Groups were "entirely ad hoc in nature. They had the proper mix of technical and management people with the decision-making authority invested in them to make on-the-spot decisions that would be backed up by program action." Membership changed as the agenda changed; they scheduled their own meetings as required. They took their cues from the visibility afforded by the monthly program reviews. They knew what the problems were because they "were there" and they set to work on them without waiting for release of minutes of the meeting.

(d) Size was typically around 15 participants in the early stages, but other attendees who needed to know what was going on (from other working groups, etc.) often pushed the total attendance up to 60. Later, as many as 50-75 participants took part. Eventually, they

got too large and outlived their usefulness as the system definition became more and more firmed up, most major decisions had been made, and most schedules and courses of action were established; i.e., a more normal management and technical task was underway.

(e) Often, tests or analytical programs were initiated to verify assumptions or to provide input data back to the working group to assist in "fine tuning on a course of action."

(f) Interorganization and contractor-government and technical-program management gaps must be "bridged" for successful working groups.

(g) Groups must operate "connected to the system as it exists."

(h) Dominant was problem solution; subordinate were organizational prerogatives.

The following quote from a key NASA technical man best summarizes the working group function:

> "Often, in a group, there was not enough knowledge of the total problem - or of their interfaces with other areas. In fact, most problems were of that nature. Often the group would make some progress and then 'stall out' on two or three key issues because they did not have the knowledge and could not agree among themselves on how they would recommend to even solve the problem. This would result in the identification of open action items. Other groups would do the same. These would be compared by management where more often than not, superimposing a few management decisions or 'ground rules' allowed the process to continue.
>
> "So the working group system worked in that it could 'kick out' problems for further solution when the scope was beyond that which the group could handle ... They were a very valuable management tool - even though many regarded it at that time as a very 'messy' way of doing business. I think I would still select that approach in a similar program...
>
> "This was a rather involved process over a 2-year program where not only did we sit and study approaches, make trade offs, and exercise judgment; we also actually instituted test programs, verified numbers to our satisfaction - even in early flight - and fed them back for comparison with analysis for further fine tuning. It was a complete end-to-end process ... a developmental management technique."

"Change-isms"

Changes are unavoidable! Two attitudes stand out in Saturn history. First is the acceptance of the evolving nature of the system - the inherent difficulty of developing absolutes of system definition, and then proceeding toward completion of that system. Ideally, perhaps this is what each of us would like to avoid, but unfortunately - and realistically - it is practically impossible. It would be better to accept the necessity of system changes as they become imminent and to develop the planning necessary to (a) lessen their impact, (b) have the flexibility in the system to adapt to change, and (c) carefully weigh each change in a risk-assessment environment rather than a dictatorial "thou shalt not change" environment.

Secondly is the fact that once system definition has "firmed up" to some type of baseline definition, considerations of the "what if we do, or what if we don't nature" must receive collective judgment assessments. The desires of many technically oriented people to "do it better" must be weighed relative to cost and schedule problems. Changes which are approved usually affect other subsystems, or the overall system, and coordination must be effected! Each decision must be looked at in a very orderly process - a very important link in the systems chain!

The change board mechanism which has various levels of change responsibility (see fig. 3) seems a very appropriate mechanism - one which has many parallels in government, school systems, industry, etc. Why then was this mechanism on Saturn successful while some others in our "real world" seem

ANY CHANGE AFFECTING MISSION CAPABILITY	Highest Approval Level
ANY CHANGE AFFECTING STAGE & GSE OR OTHER STAGES	Intermediate Approval Level
ANY CHANGE AFFECTING STAGE ONLY	Lowest Approval Level

FIGURE 3. SATURN CHANGE BOARD MECHANISM

unable to cope with change? I believe the answer lies in (a) the erroneous attitude in many real world situations which presupposes that the system, as conceived, will function as planned, (b) the use of many single-point decisions rather than collective technical assessments, and (c) the lack of ordered change mechanisms, with adequate resources. More will be mentioned of this later in this report in the section on socioeconomic problems.

In summary, an extremely perceptive MSFC key technical man made this remark:

> "Change boards were, in effect, review meetings where all the knowledgeable assessments were presented and understood. This led the board to a decision - or to a recommendation to the next higher level ... this was a very organized, preconceived fashion to supplement many areas of management ... many of the elements of good systems evaluation were certainly involved."

Sensitivity, Professionalism, Attitude: Hard To Measure, But So Important

One of the most technically qualified interviewees at the Center stated:

> "We have a lot of very capable, technically competent, engineers and scientists who do not have the slightest feel for what they are doing technically to someone else. They don't even ask the question. They assume that others will come to them! They think that 'if I do a good job on my part, and everyone else does too, on theirs; then the whole thing will work.' They are not sensitive to the decisions that they are making at any particular time, that may reflect on the characteristics of the total effort of everyone in the final analysis!"

Every one of us can profit from real self-analysis of our own selves on this matter.

There are three ways in which the proper sensitivity is developed: one is that many seem to possess it naturally; second is that, if begun in the educational process, it has a tendency to grow; third, and probably the only way to reach those who did not obtain it by one of the first two ways, is that of learning it in the "final analysis" alluded to in the foregoing quote. If this final analysis is not a part of the person's experience, then there is no way to go except for him to become narrower and narrower and less and less sensitive to others. As an example, the MSFC team experienced many "final analyses" in missiles leading up to Saturn - many times when the hardware had to produce as it was supposed to. Sometimes it did not, and lessons were learned. Many disciplines or endeavors never reach such a test; their final analyses remain theories, untested, unsensitized to the environment in which they must finally function. Now, certainly there is much to be gained by theoretical studies; many developments would never materialize if it were not for the intense efforts of many theoreticians. The point is, however, the experiences of taking a really hard, realistic look at just what is to be turned out by the group - whether it be a paper study, performance requirements, hardware, or students - is the best teacher of system awareness! The further away from actual performance in the physical world, the less effective will be the lesson in system awareness!

The most serious problems facing our society today are the result of not having such a "final analysis" as a point of focus. While NASA/MSFC had the launch stages and the Instrument Unit, and while NASA/MSC

had the command module and the LEM, and while NASA/KSC had the launch complex, many universities and social problems have lacked such a focal point. The remainder of the report following the next section relates to universities and socioeconomic problems.

The "Marshall Circle"

One way to depict visually the MSFC system influence on Saturn is shown in Figure 4. This is a symbolic circle formed from strands of wire would into a "cable" and entwined with a helical "coil." A cross section is shown also on the figure. The strands of wire making up the "cable" are the disciplines representing the technical strength of the center - of necessity strongly consisting of the material of which they have been made (their experience, education, etc.). The core of the "cable" represents the goal of the center, the internal boundary of each discipline. On the outer boundary is a helical coil, similar in concept to a recently patented Center development*: the patented item produces a magnetic field which can "adjust" what it surrounds to meet critical tolerances. To call this coil system engineering would perhaps evoke too restrictive an idea of what group performs this function at MSFC. Instead, it is really system awareness, a function that has been performed by center top management and numerous organizations, but most of all on Saturn by dedicated individuals in various organizations who realized that it had to be done to meet the goal. Certainly, this permeated the MSFC-contractor relationships also!

*Patent number 3,507,034, Schwinghamer and Bennight, Method and Apparatus for Precision Sizing and Joining of Large Diameter Tubes, April 21, 1970.

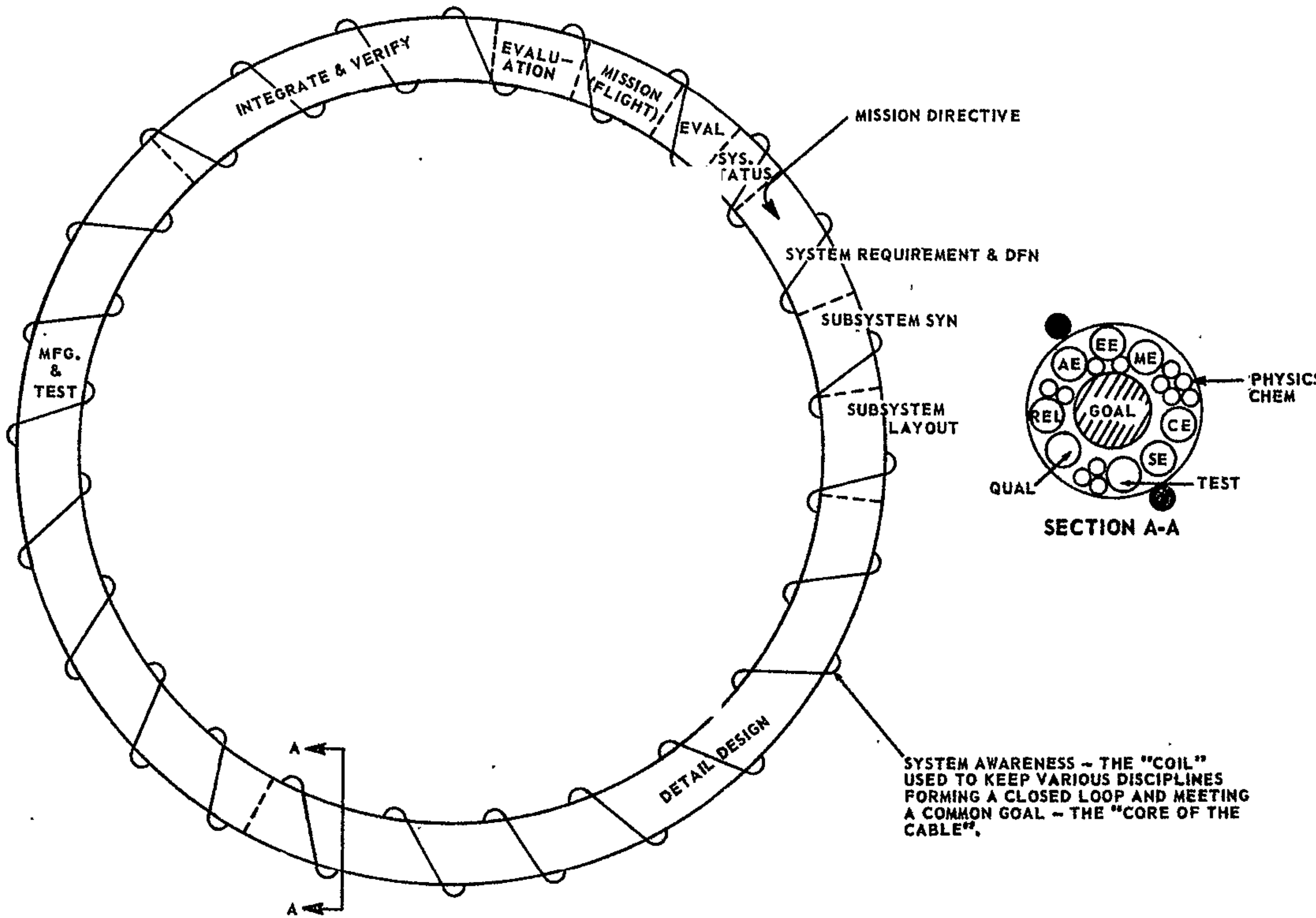

FIGURE 4: "THE MARSHALL CIRCLE"

On the closed loop - or circular form - of the "cable" are shown the many functions which comprise the center effort. If each individual in each discipline "strand" could continually be aware of the necessity for the complete circle, then successful engineering of systems can continue to be an MSFC trademark.

The "coil" function has much diversity of opinion as to who should do it, whether it should be organized or not, how to accomplish it, indeed - even what is the function in many cases! But without question, the technical management - those who have come up through the discipline areas - see an acute system awareness, with a reasonable attempt at partially organizing it, as a very realistic solution to the demands placed on the Center. Ironically, the goal - the core, and its definition; and the discipline specialists - the strands, and their attitude dictate to a very large degree the role which the system awareness (the coil) elements play. Need it be a python with its strength-sapping constriction, or should it not be more like a magnetic influence which provides an environment - a field - in which the disciplines function in structural unity? Experience has shown that as complexity increases, the need for centralization of many of the system awareness functions increases. Why prevent it from functioning by poor attitudes and organizational bickerings or the lack of an understandable goal?

IMPLICATIONS TO UNIVERSITIES

A New Role for the University?

The universities do have a new role! It is not appeasement of those who would overthrow them. It is an increased capability to cope with problems and subsystem interrelationships. Any perusal of "university happenings" during the past years would indicate many university problems (not all, of course, have sources within the university itself). While efforts must be made to eliminate external problems, we must assume that some problem sources exist within the university systems themselves. Based on the present pattern, if they do not exist in some cases at present, they in all likelihood will soon develop. The university "system" is so complex and its response so difficult to stay ahead of, that a need for a vast increase in overall system considerations is imperative. The President of the Pennsylvania State University, Dr. Eric Walker, has asked, "can colleges face the future without making some really basic alterations in the general pattern of education?"[29]

There should be, now, a look back by universities at the Saturn success to see if there are ideas that can be applied for further improvement of the individual university system. With this in mind, and considering restrictions on the volume of this report, the reader must be careful not to interpret this section to be critical; nothing could be further from the truth! The author's convictions, and his observations of those interviewed during this study are completely contrary to the goals of those who find nothing good in our present university system and who attempt to bring about anarchy to achieve their goals.

Instead, it is hoped that this report and creative applications of some of its content to individual university systems might provide the catalyst for greater success of university missions.

The University "System" and Its Products

In order to have a frame of reference for discussing "systems" with respect to universities, first, we should try to define the university system in some fashion. Can it "fit" into a recognized system definition? A NASA document[20] says a system may be "an organized and disciplined approach to accomplish a task." An Air Force document[3] states that a system is "a composite of equipment skills, and techniques capable of performing and/or supporting an operational role." Finally, Machol in the System Engineering Handbook[16] indicates that a system is something which has the following seven characteristics: (1) man-made, (2) has integrity - all components are contributing to a common purpose, (3) large, (4) complex, (5) semiautomatic, (6) has stochastic inputs, and (7) is usually competitive in some manner. Few observers would dispute numbers 3, 4, and 6, especially of late!

The tremendous support given by numerous universities during the Saturn Program on the Saturn system hardware itself certainly fits in well with the AF definition. And few would dispute the university's meeting the NASA definition. It would remain, however, to define "task" in connection with the NASA definition, and to define "an operational role" in connection with the AF definition. Can we not accept Rosenstein, who in an excellent 12-year Ford Foundation study[23] states that "...the prime responsibility of the professional school (the university) must be the preparation of men (or women) who will understand and discharge the obligations of the profession(s)"?

However, the products of most universities today do involve more than just student outputs. Research, adult education, influence on other educational systems, scientific thought, conferences, research institutes, etc., are but a few of their many diverse functions. In essence, however, <u>each function had as its origin the thought that by performing such a function, and involving university elements in such functions, they would serve to better prepare students for performing well in their chosen field upon graduation.</u> It would be naive to think that these original thoughts are still the dominant motivation today. A deeper analysis of our university system can result from a comparison of analogies and contrasts of it with respect to successful Saturn systems engineering and the further considerations of its system characteristics which follow.

<u>Analogies Between Saturn and the University</u>

There are a number of parallels or analogies between the Saturn success and a successful university system. With Machol's system characteristics in mind: certainly each is man-made, each is large and complex, and each has a certain amount of stochastic inputs. Obviously, the Saturn is semi-automatic much more than the university. Machol's meaning here is that man-machine interaction - computers and computer methods - are mandatory in operation of the system. Obviously, too, the university must tend more and more to having computers aid in system decisions, system flexibility,

and system visibility if it is going to continue in a dominant role in our society. Saturn "competed" against nature's laws and tremendous odds. Universities compete: against other universities for budget and research funds; against other resource-desiring agencies; in fact, against time in striving to stay ahead of the "response" of the entities making up its system! Finally, Machol has indicated that, to be a system, the "something" must have integrity in the sense that "all components contribute to a common purpose."

It is on this latter point that the analogy begins to break down. The university has gradually veered away from any goal which unites its "component or subsystems. This contrast will be explored further in the next section.

There are a number of analogies which space does not permit alluding to here. But, as examples, the university has similarities to working groups and the change board mechanism essentially in its committee system. An analogy exists between working panels (which performed "working group" functions between NASA Centers) and ECPD accreditation teams. No attemp will be made to compare details of these analogies here; there is too much variance between universities, and between the missions of Saturn and our colleges. For instance, the assessment of the impact of a curriculum chang is quite different from that of a Saturn hardware change. This is true in every instance where the real truth is quantifiably elusive! Contrasts in the working group arrangements are discussed in the following section.

It does seem that functions similar to those performed by Saturn change boards must receive greater emphasis in future university endeavors. Certainly an attempt should be made to obtain greater flexibility and quicker

response in curriculum and facility planning, student-faculty relations, "measuring" of teaching ability, and response to unforeseen changes in the university mission. On Saturn, change mechanisms received demanding attention and resources. If the university does not adequately recognize the change mechanism along with research and publishing, and the constant changes necessary in teaching content and teaching methods, then poor "system response" will show up at some later time. Faculty members will perform well the "change mechanism" if they feel their efforts will bring meaningful results.*

In analogy, too, the universities have many leaders in the "creative minority!" They have, however, a much less free hand in controlling the system than Saturn key leaders had. This is essentially because of inherent contrasts in the makeup and functions of the two systems and system outputs. The aforementioned contrasts in intellectual vs. physical enterprises (see p. 28) are infinitely appropriate here. It is absolutely imperative that we find ways to allow "the von Braun's of the university systems" to have more resources and more of an impact, to have a more effective means for overcoming university parochial atmospheres, to be able to "speed up" the often slow response to change; and to reward them handsomely for it! Some of the observations in this study offer excellent possibilities in these areas.

In this consideration of analogies, it seems that the university, too, often has quite a problem with sensitivity and attitude among its professors and administrators. Paraphrasing the statement (see p. 37):

> We (the university) have a lot of very capable, technically and scholastically competent professors and administrators who do not have the slightest feel for what they are doing to someone else.

*See Reference 23, pp. IV-6 through IV-8.

> They don't even ask the question. They assume that others will come to them! They think that 'if I do a good job on my part, and everyone else does too, on theirs; then the whole output of the university system will be fine.' They are not sensitive to the decisions that they are making at any particular time, that may reflect on the characteristics of the total effort of everyone in the final analysis!

The same comments relating to development of this sensitivity within NASA engineers and scientists definitely apply to these types within the university.

Finally, Table I on the next page gives further analogies.

Contrasts and Paradoxes Between Saturn and the University

Outstanding in this category are (a) often the lack of a common goal, (b) no parallel to the "working group," and (c) often a lack of visibility. The first two of these items are a direct result of the obvious trend of a university - the trend to attract, hold, and reward strong specialists. This alone dictates difficulties in items (a) and (b).

The "goal" seen by individual faculty members is that which the university "pushes" and rewards. It is usually the attainment of technical specialty strength, the very element which Marshall, itself, maintains most important in the Saturn success. But, Marshall technical management is quick to add that this, by itself, without acute awareness of the overall system and system goals greatly limits the effectiveness of this most important element - except in reaching individual goals! (An important contrast exists between Marshall's measurement of technical specialist strength and that of the university. Marshall hardware tests

TABLE I SOME POSSIBLE ANALOGIES?

Are the statements below true in our universities...	when compared to these Saturn observations?
There is an intense effort by many dedicated individuals who realize the necessity for cooperative efforts between departments in order to assure success of the system.	Item 1, p. 15: System awareness -- This was an intense overall perspective possessed by dedicated individuals who realized the necessity for cooperative efforts on subsystem development in order to assure success of the overall system.
Problem areas are addressed openly in "recovery plan" sessions.	Item 2, p. 15: Technical issues -- The concentration on these by management, working groups and panels, laboratory discipline groups, and in program reviews was without letup. Individual perceptive questioning and addressing problem issues in "recovery plans" played a very important part.
We constantly try to decide what we will do if things do not go as planned. All student failures have a reason; we always find out the real reasons why.	Item 7, p. 17: Failures -- A controlled failure attitude necessitated constantly promoting the idea, "let us do all we can to prevent any and all failures, of course; but *if* one occurs, what do we do then?" Too, failures were "planned for," or anticipated. It was assumed some would occur in testing, for instance. No failures were left unexplained!
No test or quarter or semester passes without being followed by an intense effort to extract all possible considerations to make the next one better.	Item 13, p. 18: Post flight and post test evaluation -- No mission or test firing occurred without being followed by an intense effort to extract all possible technical considerations from available data.
"Tiger teams" are used often rather than standing committees. Their recommendations are usually followed.	Middle of p. 21: "Tiger teams," short term appointments of capable individuals with related interests and diverse disciplines, were often used to pull together more needed facts to aid in joint assessments on just where problems were most likely to be. Reviews of such assessments occurred periodically.

and performances and collective personnel judgments are criteria. The university uses in the final analysis, essentially, publications. Is Toynbee's analysis of the "physical" structural unity as compared to lack of intellectual unity appropriate here? See Leadership Characteristics.) NASA itself has recognized this common goal problem on university research that was supposedly multidisciplinary and common goal oriented, but which was in effect "sliced up and parceled out" to individual specialists. For instance:

> "The multidisciplinary aspect of (NASA) research grants has generally not been taken seriously by universities. The universities perceive the grants as institutional support in a conventional sense that does not require innovation in the administration of research. A contributing factor to this attitude is the lack of 'systems' administrators in universities with broad views of real-world problems and the capability for breaking problems into small subsystems for attack... Research involving individuals from multiple disciplines, including social sciences, jointly attacking a multidisciplinary problem is nonexistent."[19]

A very strong exception to this observation is the NASA/ASEE Summer Faculty System Design Programs. Reference 28 describes the 1969 program at MSFC directed by Auburn University. Individual faculty members will function as a multidisciplinary team if pilot team efforts receive recognition on a par with individual research efforts.

The lack of a common goal could have several solutions. One would be for the university to reward part specialist - part generalist faculty members more. Another would be to have more interdepartmental teams working together in common efforts, both research and teaching! In connection with the latter, some better means to convey system awareness to our students (and faculty, too) must be developed. A key MSFC electrical

engineer stated it thusly:

> "System engineering is an activity that you develop from the very beginning. One needs to end up sensitive to the fact that the design being done has to 'live' in the real world with other designs. This is a legitimate criticism with engineering education - when a student is taught to design a gadget, he must also be taught to consider more than just how well it does <u>its</u> job. How well can it really fit into the real world? How <u>well</u> can it be maintained? How well can it be integrated into the overall system of which it is a part?
>
> "Some people just naturally tend to do things simply. Others tend towards sophistication; many towards sophistication for its own sake. If a man is sensitive to the fact that the system exists for some purpose other than its own existence, and that it has to work with and be controlled by other things - if he is sensitive to variations in other subsystems - then it is a much broader outlook. If this were instilled in subsystem teaching and allowed to grow, then we would have 'automatic' system engineers when we get through.
>
> "The 'sophistication' that starts occurring in later courses in college gives sort of a feeling of accomplishment in itself that leads to more of the same, but that very sophistication hides the very basic engineering we would like to get out of people! It's not that we don't need a certain amount of sophistication at times, but it must be in its place. One cannot get much more basic or fundamental than to develop - within engineers, scientists, professors, and students - a sensitivity to others' problems as he creates his own designs and generates problems for other people."

One way to attempt to do this involving students would be to develop more interdisciplinary team effort studies - probably involving case studies. When and how this might occur would perhaps be the subject of many diverse opinions and, of course, many examples exist at present. The best stated consensus ideas from the interviews, however, are:

> "I'm not real sure of how well case studies work in undergraduate education, but I <u>do</u> know that when you have a cadre of people together with expertise - that you can learn an awful lot by trying to understand the other guy's technical viewpoint, which is the beginning of system engineering."

"It would appear to me that we must assume that an engineer has been through one of the more traditional disciplines. On top of that, he needs to develop a tolerance for other viewpoints. There's nothing more intolerant than a person who has just received his degree in a certain field or even worse - one who's worked in it (just in it) for a few years. He has lost all contact with other considerations and other inputs. If there were some way to get these people exposed to the large variety of things which shape final decisions in some meaningful fashion. I don't think you can do it with a classroom approach too well. You need more classroom assignments where case studies are pursued, where actual problems are studied, where seminars are done properly. One could possibly construct a course around a series of problem situations where a group of discipline-oriented people of the right mix are thrown together on a problem and have to sort out all the parameters which have to be understood in order to make a decision, and have to participate in that process. And require each of these people to operate completely outside of his discipline area in doing this. He has to see that his discipline is there - and believe in it - but he is not able to call on his own resources for strength. Yet, he must participate in really identifying the key trade-off factors which have to be studied and understood and which relate to a decision. To me, the decision making process itself is the very essence of systems work; the understanding of what you have to understand to make the decision and how to go about getting the facts, and how to understand and interpret them. A banding together of several disciplines and a trial on several problems which are known to have all the proper attributes would be the best way to proceed on the undergraduate level. As many existing examples as possible where the outcome is known should be utilized."

One other point in connection with this lack of a common goal aspect: NASA executives indicated that "one must look at the conglomerate of the organization as a measure of the tool that you have." It would be naive to suggest that the university does not agree with this in principal. But, in reality, this is a very difficult frame of mind to maintain. Some parts of the "conglomerate" are better researchers; some are better teachers; and some are more prolific at publishing than others. Some fields are inherently more difficult in which to become established. The tendency, however, is

to "measure the tools" through use of those products which lend themselves to easiest measurement, usually publications and degrees (similar to number 9, p. 24). There must be a role for some non-Ph.D's and for professors with good practical experience. The best conglomerate need not be an all Ph.D. faculty which has experienced only an academic background in its development.

The second contrast is that there is seldom a parallel to the "working group" concept within the university. One must understand just what role the working groups played within the Saturn Program to recognize all of the implications of this statement, so that section in a previous part of this report should be perused thoroughly. Certainly, there are attempts within the university to fulfill this function, but in general, they do not include the individual faculty member on a plane or to the extent that NASA Saturn/Apollo working groups involved the individual technical specialist. Part of the problem is the emphasis on the vertical management structure of the departmental organizations with little intercommunication between similar specialists in different departments. This "feeds" the already existent problems inherent in having an organization of technical specialists in the first place. While the competition inherent between these organizations has some merit, the "competition" to collectively work as a team towards the accomplishment of some well coordinated goals has greater merit and usefulness. And it need not drastically diminish individual accomplishment goals! As examples of these points, several key

MSFC technical managers have the following comments to offer; their appropriateness to universities is very evident even though the comments were made in relation to the Saturn Program:

> "Often, meetings with all system elements were held in one room (Mission Planning Working Group). It was decided in this meeting who needed to do further studies. One reason for these decisions was to conserve resources, to depend on everyone in the system knowing what the others were doing, so that each job would be done only once-- and yet all parts would fit together. (It hasn't always been done this way; when more resources were available, a job could probably have been done at five different places and comparisons made.)"
>
> "People understood that they were not working in a vacuum and that they had to trade off with others--they could not make arbitrary decisions. Often though, detailed technical specialists will look at too narrow a field, particularly in the lower elements of the organization where they do not have an opportunity to see the big picture. That is one reason why communication channels must be kept open--all the way up to the top."

The tie-in of this contrast in working group concepts with generalists-specialists problems and with difficulties in goal focal points is very real.

A third sharp contrast concerns visibility. Certainly, this may vary considerably from university to university and from level to level. But, generally speaking, NASA views this as less of a frill and of more importance than does the university. One very important reason for this has been the menial budgets available to many universities during the long "push" to bring faculty salaries up to respectable levels. Visibility is one of those areas that just takes a certain amount of funding to do any good at

all and has been treated as secondary at universities. Its use in highlighting problems and staying in tune with responses of the system is just as appropriate and needed in the university system as it was, and is, in Saturn. Too often, it is "one of those things one needs to do," but somehow gets left behind in the race to do the things one has to do. And yet, it can mean the difference between right decisions and wrong decisions, between "controlling" the system or losing control, or between successful system output (students) and subpar output performance.

Several suggestions concerning the visibility role of the university would be: realistic time line analyses of faculty workloads, flow charts or charts similar to PERT/CPM use for student milestones in meeting degree requirements, etc., and course sequence and prerequisite wallboards showing content and interdependence of courses. All of these are usually covered in a mass of catalogs, files, or in minds of individuals on campus, but clear visibility would make for a much more efficient system. While computers are used extensively in universities today to aid in handling masses of data, an order of magnitude increase of visibility of this data must occur with respect to the system output, the students. Other than individual counseling, usually on an asked-for basis, there is little visibility used to highlight upcoming student problems--technical, social, or otherwise. Computer and computer graphics

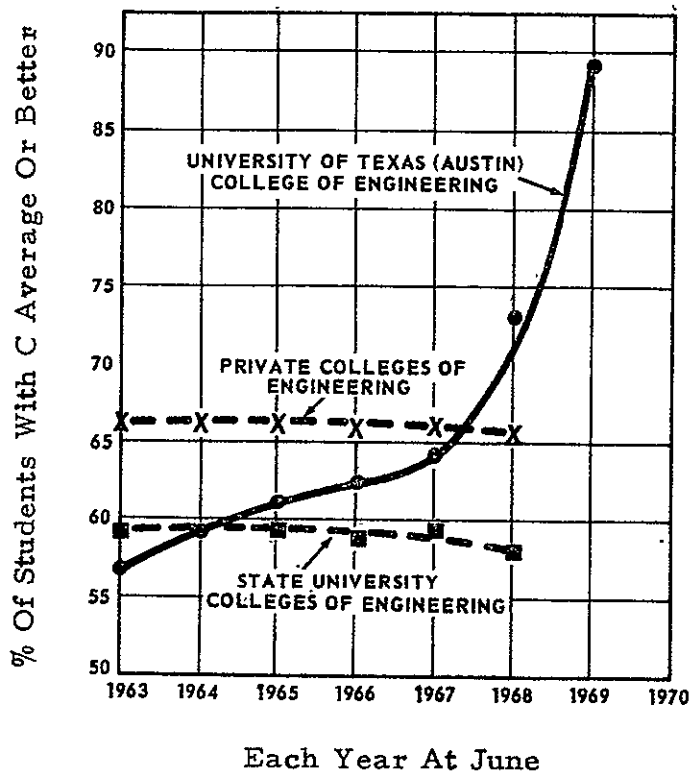

FIG.5 PERCENTAGE OF UNDERGRADUATE STUDENTS IN GOOD STANDING AT END OF EACH SCHOOL YEAR.

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could be used with trend analysis to gain a significant increase in measurement of how our "product" is coming along in performance.

For example, while not completely "tied" to visibility, figure 5 gives an indication of what could occur when a real conscious effort is made at using visibility in classroom teaching (including the availability of illustrators, etc., being made available to faculty). This particular figure is a plot of the percent of students with a "C" average or better versus years for two classes of engineering schools, and the engineering school where this program was put into effect.[18] The tremendous increase in motivation necessary to achieve such results <u>can</u> occur when visibility is used. Interestingly though, as in Saturn, it is <u>concern for eventual good performance of the output product</u> that is the motivating influence behind visibility use! As with almost anything, visibility for visibility's sake is <u>not</u> the answer. To get existing people to change their way of doing things will require an extreme concern for the final product and the role which visibility can play in the development of that product!

A SMALL STEP FOR EDUCATORS: A GIANT LEAP FOR EDUCATION

The collective outputs (people) of university systems, some American and some European, dominated the Saturn success. These "alumni" of Saturn do not look at education and condemn it. But they do feel that there are improvements - to varying degrees - which could be made in much of education to have a tremendous impact for enhancement of a deeper sense of professionalism among our future engineers and managers.

From within the ranks of education itself, Eric Walker, president of Pennsylvania State University and the National Academy of Engineering, outlines many steps towards this end in reference 29. His discussion of the "inadequacies of the (university) system" and the "need for real change" must receive our demanding attention. In summary, he points out that our university systems have "failed to question the fundamental validity of many basic concepts," especially those related to standardization of many methods and traditional patterns which lead to student impersonal feelings. He states that "many practices are based upon time-honored conventions which are never questioned. They hem us in for no good reason. It is merely that things have always been done this way." Among these practices mentioned are (a) years of study required for degrees, (b) course credit problems, (c) lecture length, and (d) problems with the lecture idea, itself. Constraints of course updating, schedule, classroom problems, and the economics of teaching are

discussed. Finally, Dr. Walker calls for an "increase in productivity in American education" and release from "operational procedure that has held higher education in the kind of bondage it has been in for so many years."

The elements essential to the Saturn success and delineated in this study can provide effective guidelines for this break from tradition. Only through the von Braun's of the universities and changed attitudes of faculty can the environment for more effective university "working groups," "change boards," visibility, and system awareness be promoted by the university. It must be a top-to-bottom function. Realistic solutions for university problems can and must be obtained. "Small steps" by each member of the "university team" can provide a "giant leap."

CAUTIONS AND ANALOGIES FOR SOCIOECONOMIC PROBLEMS

"All problems, when solved, are simple!", a favorite professor of mine often said. In this frame of reference, MSFC technical management is divided as to whether the solution to some of the present socioeconomic problems of the United States (and of the world) will be easier or more difficult than putting a man on the moon and subsequent space activities. But they are in complete agreement that there are many transferable techniques, attitudes, philosophies, etc., that could have major significance in solution of our socioeconomic problems! (This class of problems is intended to include, but not be limited to; air pollution, water pollution, urban problems, transportation system problems, etc.)

First, and very important, is the point that while technology may be held at fault by many for causing these problems (often unjustly), it is through some advance in technology that a major part of the solution can usually be found. For instance, in pollution of the air by the automobile engine, some technological means to enable an energy source to generate power without polluting must be a very important element of solution! In this respect, NASA has much technology which is appropriate; it is not the intent of this report to deal with such. Only someone who is woefully ignorant of the facts could dispute such a claim. The point is, that all the public interest, congressional pressures, etc., will not supplant technical capability and rigor. A reemphasis of the

three must basics of the INTRODUCTION of this report is strongly made in this respect. Very closely tied to this is instrumentation used to obtain data. Decisions cannot continue to be made so much on opinion or "do-gooder" philosophysing, in the socioeconomic area.

The consensus of all interviewees was perhaps best stated by the following:

> "It would be hopeless to try to solve some of these (socio-economic) problems without using a systems approach. First, define the problem exactly, and how you are going to develop the solution, properly and scientifically gather the data, understand the validity of the data, test it and check validity if necessary. Then lay out a logical well-ordered process of coming to a decision..."

On the other hand, many expressed concern at the typical fill-in-the-blank comment, "Now that we've been to the moon, we can ________." Nothing could be much further from the truth in many instances. While the Saturn Program was certainly not devoid of people problems and political problems, many contrasts between the different types of problems do exist which will require traversing a very bumpy road of experience before success will be enjoyed.

In somewhat of a chronological order, some of the problems and pitfalls which face our nation, and our world, in solving the socioeconomic problems can be stated as follows. There is the difficulty of obtaining a consensus on just what goals should be. Connected to this is a superficial look by many John Q. Publics, and a complete lack of realization of time and money constraints in attacking problems. Many

want to take steps 3 and 4 before taking steps 1 and 2. Most do not accept the reality of Murphy's Law* in socioeconomic problems - which those of us in engineering have learned by experience to be often realistic. The human problems which are at present so difficult to quantify will greatly influence success of even carefully thought out systems approaches. (A recent article (10) discussed how importantly an individual's desire to 'control his own locomotion' has influenced the 'failure' of so many - even well designed - mass transit systems to date! Another example is that the role of human emotions in transportation problems - those on land and the SST type - is extremely difficult, if not impossible, to simulate mathematically. Self indicting, of course, are many examples which show that giving financial help alone to many individuals does <u>not</u> take care of the problems for which financial help was opinionated as <u>the</u> solution!) Perhaps this point could be more vividly illustrated by asking ourselves, what complications would occur (aside from greater technical problems) if the Saturn/Apollo Program goal now were one of transporting the U. S. population <u>in its entirety</u> to the moon? The <u>human</u> problems in such a venture are not too much more difficult than in some of our socioeconomic problems.

What next then, assuming that goals can be established, and some basic decisions made to apply resources within a long enough time frame

*Briefly, "if anything can go wrong, it will go wrong." (A corollary is "and it will right away!")

for problem solution? Will there have to be a skipping of intermediate or early steps in order to arrive at some unreasonable evidence of success in order to assure continued support? Will steps that are too big be attempted? Will abrupt curtailments of large projects begun with enthusiasm take such a wasteful toll in careers (individual and corporate), and in the resultant human misery that follows, that many will wonder at its worth?

Visibility and individual responsibility are the key elements from this point on! Indisputably there must be more than the present cry, "We must stop pollution." Good plan and problem-piece definition must exist with some focal point for various groups attacking the problem toward which they may orient themselves. Organizational interfaces must be described with the necessity for reaching a realistic solution ever in mind; with some means for groups to get together![21] Someone or some organization must be looking at the optimum solution! For instance, in reference to the socioeconomic problem of pollution, Lenher in ref. 14 has observed:

> "What is lacking, most basically, is a clearly defined national policy on the environment, a straightforward statement of what we are trying to achieve...this can only come from the Federal Executive...time is running out...now we must clean up the mess. The question is not whether, but how...industry has the job that is easiest to define...the university role (is)...as important as industry's..." We need "more sharing of ideas across company and industrial boundaries, and more cross-links to university and government laboratories...we need to change our patterns of technical thought, to approach the problem in the round, in terms of resource use and overall environmental impact.

"What is still unclear is how university resources can best be applied... There aren't any neat answers or obvious ways to organize this. The environmental program is larger than any single discipline or university department... But at the same time, each discipline has some special tools that apply to specific parts of the problem, and the tools aren't made of interchangeable parts...

"How we merge these talents where they must be merged, and still keep the tools separate where they are discrete, is a neat question..."

In this problem of pollution, as well as in many other social problems, the implication that success is equated with profit is an attitude that will not be easily overcome. But the Saturn experience would dictate that this equation should be technical <u>truth</u> equals <u>success</u> equals <u>profit</u>!

In many other socioeconomic areas, the influence of strong subsystem people, who "flaunt" their particular subsystems with no regard for the system has been very evident in the news lately. In the Saturn Program, these types could be "quieted," or made to see, by engineerin test results. But how does one win over those who openly admit their desire to rip asunder the system with little "reason" behind them? Perhaps the truest test of a system approach will be to find ways to convince these people that they <u>are</u> a part of the system and they can contribute useful ideas toward a successful "system" rather than tear it down and replace it with their own "subsystem."

An irony of ironies would be for teams to apply the systems approacl in attacking problems involving human beings, while failing to recognize the spiritual "subsystem" and its tremendous influence on the hearts of men. Many are the problems which will defy solution without changes occurring within hearts of individuals!

Finally, to ignore the influence of education and the news media on all of these problems would be naive. The human tendency to <u>really</u> learn only by experience and mistake may be the only way we as a nation will learn the power of such influence. The following quote from a foreign born engineer-scientist who saw irresponsible use of such influence destroy a foreign nation speaks more eloquently than many volumes:

> "Great is the power of speech, great is the power of printing... the biggest danger in this country (any country) today is the power of television, radio, mass media communication. It can be a wonderful tool, but a very dangerous tool... Education and mass media can do wonderful things - and can destroy a nation!"

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APPENDIX

It has been the intent that this be a tell-it-like-it-is report; done with the belief and hope that NASA/MSFC does have-what-it-takes to meet the space (and many non-space) challenges of the future. While there is an emphasis upon what is good about systems as opposed to what is bad, the study should not be taken out of the context that dedicated technical competence is assumed, not disregarded!

In the beginning, a study of much of the literature on systems engineering was undertaken. This has played an important part in the author's background in the subject. The author's attendance and/or familiarity with several system engineering courses contributed to this considerably, too. A RSIC search on systems engineering yielded 434 pages of printout of source literature. Most of this consists of technical application reports; little on methodology or "how to do it." The 148 pages of printout on man-machine systems was similar, with many duplications. Many of the best documents were unlisted, but were uncovered in informal contact with various people.

Perhaps a debatable assumption made in the beginning was that of not developing a questionnaire or formalized interview routine. It was felt this would limit the outlook of the overall study. Encouragement was given for each individual interviewed to delineate what systems engineering meant to him, ways and means of achieving the Saturn success, pertinent illustrations or documentation, and key techniques

or factors with which he was familiar. In addition, some ideas relative to engineering education and the role systems engineering should play in it were solicited. Finally, due to the present national interest in socioeconomic problems, the delineation of problems and pitfalls which Saturn people could foresee in application of the systems approach to them seemed an appropriate interview topic. It is possible that a quantifiable approach to interviewing would have been better, but hopefully, what has been done is closer to reality.

Some faith in NASA/MSFC's promotion schemes has certainly been instrumental in acceptance of interview ideas. In other words, it is believed that most of what the middle to upper management people said is an outgrowth of their varied backgrounds and is important, therefore a consensus was not necessarily required.

Primarily, those interviewed are listed below. Only a very few contractors were contacted as the emphasis was kept to MSFC.. Quotes have not been identified with any individual and since others were interviewed who are not listed here, quotes need not have come from those below. Most of them did, however. Time did not permit interviewing others who would have had significant input.

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J. A. Bethay - Director, Center Plans and Resources Office, A&TS-CP-DIR
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K. K. Dannenberg - Contract COR, Space Station Task Team, PD-SS
P. T. Farish - Manager, Systems Safety and Manned Flight Awareness Office, PM-SS-MGR

R. E. Godfrey - Manager, Saturn Program Office, PM-SAT-MGR
E. Goerner - Director, Preliminary Design Office, PD-DO-DIR
J. C. Goodrum - Director, Advanced Program Support Office, PD-PS-DIR
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W. R. Marshall - Chief, System Layout and Integration Division, PD-DO-S
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